

ANALYSIS OF EMULSION FUEL SPRAY CHARACTERISTICS USING OPTICAL
ACCESSIBLE CHAMBER

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ABSTRACT

This thesis deals with the study about the emulsion fuel spray characteristics using the optical accessible chamber. The Computational Fluids Dynamics (CFD) is used to illustrate how the spray developed in the chamber and the spray characteristic could be predicted. The overall macroscopic spray characteristic such as the spray penetration length and the spray cone angle were measured manually. The different percentage of emulsion fuel is used; 5%, 10% and 15% of emulsion is tested at the same injection pressure 70MPa which is high pressure and 1MPa of high ambient pressure in the chamber but in different size of nozzle diameter; 0.2 mm and 0.6 mm. The development process and the timing injection in the test were very similar. Moreover, 15% of emulsion which is a higher percentage of emulsion fuel induced shorter penetration length at smaller nozzle diameter and wider cone angle at bigger nozzle diameter. However, there are discrepancies of the result due to improper boundary condition and inherit limitation of the model. For further study process, the emulsion process should be done by the owner-self so the more data from experimental work is needed such as properties of emulsion could be implemented in the study.

ABSTRAK

Tesis ini berkaitan tentang kajian mengenai karakteristik atau ciri-ciri semburan bahan api emulsi menggunakan kebuk optik yang boleh dilihat. Computer Fluid Dynamic (CFD) digunakan untuk menggambarkan bagaimana semburan di dalam ruang kebuk terhasil dan ciri- ciri semburan boleh diramal. Ciri-ciri makroskopik keseluruhan semburan seperti panjang semburan dan sudut kon semburan diukur secara manual. Peratusan bahan api emulsi yang berbeza digunakan; 5%, 10% dan 15% diuji pada tekan suntikan yang sama iaitu pada tekanan tinggi, 70MPa dan tekanan di dalam kebuk (ambien) yang tinggi iaitu 1MPa. Namun ia diuji pada saiz diameter yang berlainan iaitu 0.2 mm dan 0.6 mm. Proses penghasilan semburan dan masa suntikan dalam ujian adalah sama. Selain itu, 15% emulsi yang mempunyai peratusan air yang lebih banyak mendorong panjang semburan yang lebih pendek pada saiz diameter yang kecil manakala sudut kon yang lebih besar pada saiz diameter yang besar. Walaubagaimanapun, terdapat perbezaan pada keputusan akibat nilai yang tidak tepat dan juga keterbatasan model. Untuk proses kajian pada masa hadapan, proses emulsi harus dilakukan sendiri supaya data yang terhasil lebih tepat seperti karakteristik emulsi untuk digunakan dalam kajian.

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LIST OF SYMBOLS

d_i	Discrete Buble Size
S	Spray Tip Penetration
t	Time
P	Pressure
ρ_g	Working Fluid Density
T_g	Working Fluid Temperature
d_o	Nozzle Orifice Diameter
ρ_l	Density
U	Velocity
θ	Cone Angle
L	Liquid Length
D	Nozzle Hole Diameter
SMD	Sauter Mean Diameter

CHAPTER 1

INTRODUCTION

The high prices and usage of the fossil fuel causing a major problem around the world. Continuous rising price due to the fast depletion of fossil fuel resources has led to increasing research on alternative fuel. Energy consumption based on fossil fuels contributes to environmental pollution. Negative impact on the environment occurs from oil when dug from the bowels of the earth, processed into fuel for various purposes in refineries, burned in the engine and discharged through the smoke. One of the main reasons that alternative fuel is so attractive is that conventional fossil fuel supplies are running out. The evidence for this is presented in the case for the “Peak Oil” theory that has been confirmed by many experts. As oil, coal and natural gas supplies become limited there is going to be a shortage of energy resources.

As one of the different solutions to these problems, emulsion fuel technologies have received close attention as an alternative fuel. Appearances of the emulsion fuel which reduces smoke and save oil has enlightened a green signal to solving the resource problem and prolong the reduction of fossil fuel. Emulsion fuel is a fuel of new concept made by mixing water and oil. However, there are some differences in physical parameters between emulsion fuel and diesel fuel, and it is necessary to study the spray characteristics of emulsion fuel in relation to its application in internal combustion engines (ICE).

The present invention relates to an emulsified fuel. More specifically, it relates to an emulsified fuel, which is characterized in that it is achieved by mixing combustible fuel with water containing special components (surfactant) to optimize the combustion of the fuel. Combining water into the fuel as an emulsion provides opportunity to use water in diesel fuels in the current structure of diesel engine vehicles with no major modifications of the engines. Furthermore that it allows regular diesel to

be easily replaced by an environmentally preferable alternative without changing the existing fuel supply infrastructure.

One of the practical ways to tackle the problem stated is to study the macroscopic and microscopic of emulsion fuel spray to ensure high engine performance with low emission level. The geometrical or ‘macroscopic’ spray characteristics can be obtained with an experimental technique based on the analysis of direct photographic imaging. In addition to this, macroscopic characterization is more consistent, since they are in bigger dimensions and easily detectable.

1.1 BACKGROUND OF STUDY

The aim of this study was to illustrate the liquid atomization of the spray influential parameters on the spray characteristics using a different ratio emulsion blend (mixing water and oil) to enhance and optimize their applications to future engine also provide experimental data to allow the validation of CFD (Computational Fluid Dynamic) spray modeling program. In addition the data were acquired in a format that could be used to develop new models for the spray break-up process.

1.2 PROBLEM STATEMENT

All life on earth is sustained by energy. Plants and animals can store energy and some of this energy remains with them when they die. It is the remains of these ancient animals and plants that make up fossil fuel. Fossil fuels are non-renewable because they will run out one day. Burning fossil oil generates greenhouse gases and depending on them for energy generation is unsustainable.

The emissions of conventional fuels such as gasoline and diesel are essentially related to spray combustion. Therefore, is important to know fundamental spray properties to develop low emission combustion. If the spray characteristics of fuels change significantly combustion chamber must be redesigned or injection parameters

must be re-optimized. The knowledge of spray characteristics gains more information from the combustion phenomena and influence of injection parameters.

One of the main challenges to introduced new alternative fuel is to understand the behavior of the fuel spray distribution and vaporization. The spray structure and targeting must be optimized to evaporate in a short time and be distributed in a desired manner, under various injection parameters and variety of ambient gas temperature.

The atomization process is however extremely complex to model have used many techniques to measure including optical. In order to understand the fundamentals of fuel spray and characteristics, Computational Fluid Dynamic (CFD) spray modeling program has been used to illustrate the spray in the optical accessible spray chamber.

1.3 OBJECTIVES

Generally, the objectives to be achieved in this project are stated below:

- i. To simulate the direct injection spray process using emulsified fuel
- ii. To study the spray penetration length
- iii. To study the spray cone angle

1.4 SCOPE OF WORK

This project focused only on:

- i. Illustrate the spray images with different percentages of emulsified fuel
- ii. Investigate the spray penetration length and spray cone angle of emulsion fuel spray with different size of nozzle diameter
- iii. Result comparing with different size of nozzle diameter

1.5 PROJECT FLOW CHART

Progress work of this project is summarized in form of flow chart. Chart contains work and task of Final Year Project 1 and 2.

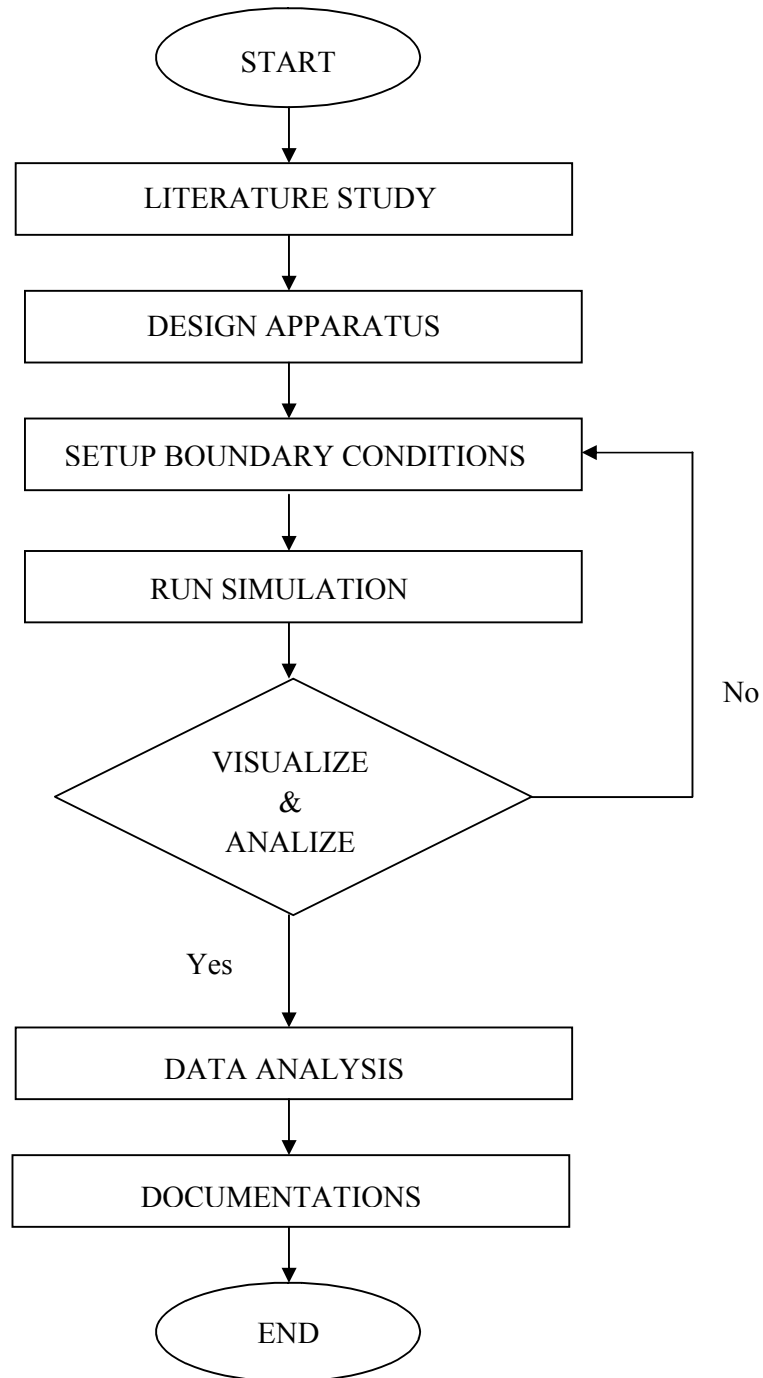


Figure 1.1: Project Flow Chart

1.6 OUTLINE OF THE PROJECT

This thesis consists of five main chapters, introduction, literature review, methodology, result and discussion and the last part is the conclusion and recommendation. In Chapter 1 presents some findings that lead to the problem statement, objectives and scopes. Chapter 2 is literatures review that related to the study and as a study framework. In Chapter 3, presents the CFD code of ANSYS fluent together with the spray model used, which relates to high pressure sprays. Then, Chapter 4, addresses the validation of predicted results, interpreted the data and analyzed also including discussion. The final Chapter 5 would summarize the main result and conclusion and outline the suggested path for future work. Gantt chart was given in Appendix.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

An emulsion is a mixture of two non-mix fluids. For example, oil phased emulsion features water droplets - the dispersed phase - uniformly distributed throughout the fuel oil - the continuous phase. An emulsion takes on the characteristics of the continuous phase. Hence, oil phased emulsions display characteristics of fuel oil, not water.

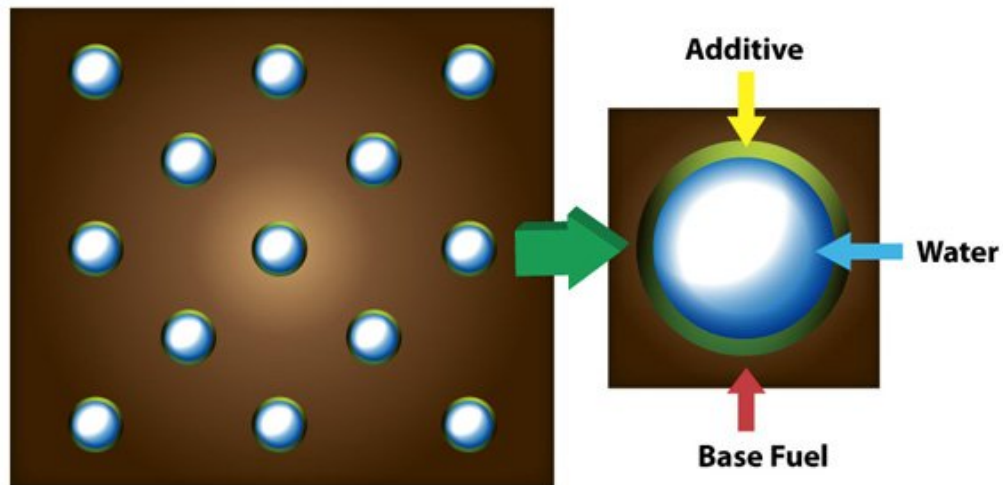


Figure 2.1: Diagram illustrating an oil-phase emulsion
(Source: <http://www.altpetrol.com/en/4a-tech-overview.html>)

Figure 2.1 shows the diagram illustrating an oil-phase-emulsion. Emulsion fuels are blend of traditional liquid fuels such as diesel, naphtha, heavy fuel oil or biodiesel and water. The water is present as the droplet of microscopic size, distributed throughout the base fuel. Actually emulsions are naturally unstable. Over time they will separate into the stable states of the dispersed and continuous phase materials. To

maintain the composition of an emulsion, surface active agents “surfactants” or additive, are included into the production of an oil phased emulsion. In oil phased emulsion, these surfactant agents coat the droplets of water distributed during the continuous oil phase and prevent the water droplets from coming together and coalescing. However the type of surfactant gives an impact to the viscosity of emulsion fuel.

Emulsion fuels refer to the emulsified mixture of petroleum-based fossil fuels, including gasoline, light oil, heavy oil, kerosene and waste oil, and water. A mechanism which is expected to react in the fuel emulsion, which improves the efficiency of fuel combustion, was caused by a mixture of the emulsified water. To provide this mechanism, various production devices has been proposed, although there has been no single technology developed that achieve a satisfactory level.

Many studies on emulsion fuels expose that it has various benefits, including improvement in combustion efficiency and a reduction in particulate matter (PM) and nitrogen oxide (NO_x) emissions. In fact, water particles vaporize and are energetically spread when emulsion fuels are ignited in an internal combustion engine and a boiler. The oil particles surrounding the water particles are also spread and become finer with smaller particle sizes. Oil particles have more contact area with oxygen, and as a result, incomplete combustion is covered and combustion efficiency is improved. As a result, PM emissions are also reduced.

Emulsion fuel gives more benefits such as cost saving, emission reduction and impact on engine performance. For more common examples, greater consumption of oil products causes greenhouses, global warming, haze atmosphere and increased environmental temperature have placed very serious financial problems in public. This is due to the impact of energy consumption from industrial base combustion structures and vehicles. Clearly, more efficient use of fossil fuels is one of the most critical challenges for people in order to save energy resources, prevent global warming, resurrect industry, and increase productivity relative to cost. Emulsion fuel technology is considered one of the most promising solutions to the conservation of fossil fuel.

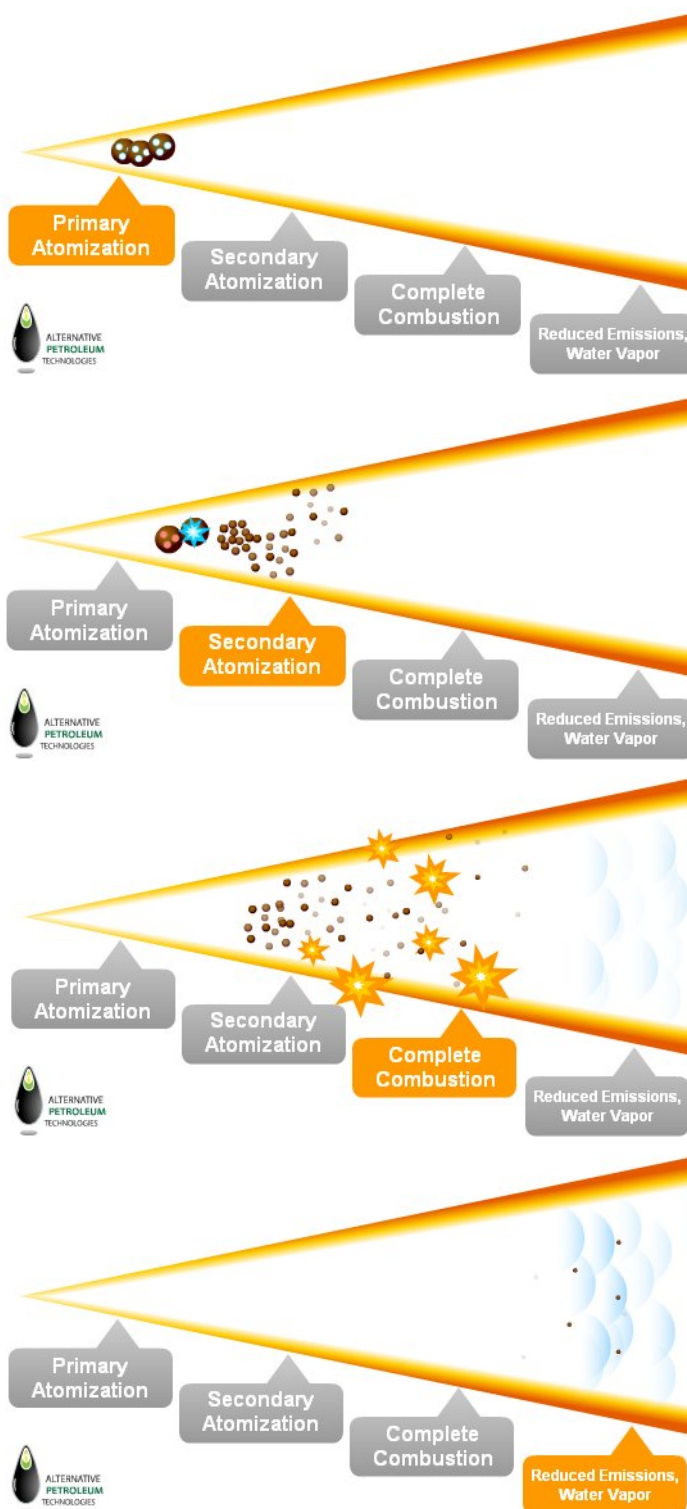


Figure 2.2: Emulsified fuel combustion process

(Source: <http://www.altpetrol.com/en/4a-tech-overview.html>)

Figure 2.2 shows an emulsified fuel combustion process. Unlike base fuels, when emulsified fuel droplets are sprayed into the combustion chamber, they are atomized a second time as a result of the aggressive transformation of their water content into steam. This transformation of water into steam breaks the droplet surrounding that water into much smaller droplets and complete combustion will occur.

Smaller droplets have a much greater surface area, significantly improving the efficiency of combustion. This unique combustion characteristic of emulsified fuels is commonly referred to as “secondary atomization”.

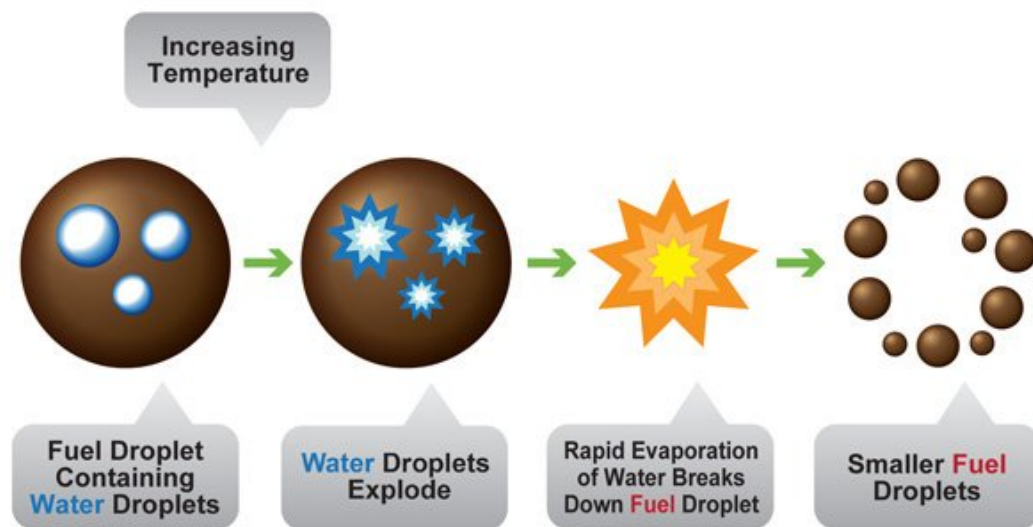


Figure 2.3: Secondary atomization development

(Source: <http://www.altpetrol.com/en/4a-tech-overview.html>)

Figure 2.3 shows the secondary atomization development. Secondary atomization occurred when the water contained inside the emulsion fuel will explode (water has a lower boiling point) that resulted in the dispersion of smaller droplet which increases the surface area between fuel and air. Combustion is more efficient due to smaller fuel droplet which results in less unburn fuel and the forming of "soot".

2.2 LITERATURE REVIEW

In this study, we explored how the various conditions including fuel viscosity and state of the ambient gas pressure also size of diameter nozzle injector affected the overall spray characteristics of an emulsion through analysis of the spray tip penetration and spray cone angle.

Depending on the mechanism to characterize, fuel spray can be investigated in a macroscopic or microscopic point of view. With the purpose of understanding in detail this process, the various physical parameters involved during the transition of a pulsed fuel spray will be expressed in this chapter.

Spray tip penetration is most fundamental characterization among the others. The spray liquid penetration starts from zero velocity at the nozzle exit and reaches maximum velocity at around breakup time. The spray tip penetration rapidly increased in the early injection stage, as the supply pressure increases, the initial spray tip penetration increased (Jeong, 2007). And the increase of the spray tip penetration slowed as the ambient pressure increased (Kim, 2010). Spray cone has wider angles at the initial stages of spray evolution. Cone angle decreases as the spray penetrates, and, after the spray developed enough, the spray cone angle settles to a constant value. Spray cone angle increase as the ambient pressure increase (Metin, 2011).

Increasing the injection pressure causes premature droplet break-up within the jet, which results mainly due to the cavitations at the nozzle exit. If them working fluid density in the combustion chamber increases, the penetration length is shorter and the second break-up regime is delayed due to the free shear flow between the working fluid and the fuel jet, which produces higher evaporation rates of droplets from the diesel jet (Martínez-Martínez, 2008). However the break up time of the fuel spray jet is independent of the chamber air temperature (Mirza, 2007).

Based on previous studies of emulsion fuel researchers, they found that a higher degree of premixed combustion causes rapid evaporation mechanism lead to enhanced atomization process (Ochoterena, 2010). Regarding the atomization and evaporation

characteristics, the overall SMD increase with an increasing fuel temperature and ambient gas temperature where the evaporation actively occurred and form small droplets as fuel temperature and ambient temperature increased (Park, 2010).

Furthermore, fuel reformulation, by altering the physical or chemical composition of a fuel, has been used as a pollution control technique and continues to be considered as one of the more preferred avenues for realigning emissions in the future. Technology includes increasing fuel efficiency, wider use of alternative fuels and using fuel additives to improve the fuel quality (El-Sinawi, 2010).

In case of emulsion itself, it should be noted here that the use of the emulsion fuels that contains too much water can never be a good energy-saving technology owing to the increase in the fuel consumption rate due to the large decrease in the combustion efficiency. The content of water in the emulsion fuel, therefore, should be determined and controlled appropriately for the kind of base hydrocarbon fuels, and never be increased so much for the long and safe running of the combustors without any trouble. For the emulsified fuels of light oil and A-heavy oil, the appropriate water content will be less than about 10 vol.%, and less than about 20 vol.% even for the emulsion of C-heavy oil (Ishida, 2005).

A reduction in nozzle diameter yields a shorter spray penetration length because it causes in advance start of the second break-up regime. Increasing the injection pressure provokes premature droplet break-up within the jet, which results mainly due to the cavitations at the nozzle exit. If the working fluid density in the chamber increases the penetration length is shorter and the second break-up regime is delayed due to the free-share flow between the working fluid and the fuel jet, which produces higher evaporation rates of droplets from the diesel jet (Martinez, 2010).

However, spray liquid penetration decreases as the ambient pressure or temperature increases. Higher injection pressure, lower injection quantities have increasing effect and conical nozzles (divergent and convergent) have decreased effect on spray liquid penetration (Taskiran, 2010).

Moreover, the evolution process of biodiesel and DME sprays developed more slowly with increasing ambient pressure. The spray tip penetration rapidly increased in the early injection stage, and the increase of the spray tip penetration slowed as the ambient pressure increased. The biodiesel sprays according to the ambient pressure had larger spray tip penetrations compared to DME sprays. Also, the spray cone angle of the biodiesel spray was wider than that of the DME spray and the spray cone angles of both sprays increased with the increasing ambient pressure (Kim, 2009).

2.3 MACROSCOPIC CHARACTERISTIC

Figure 2.4 shows the definition of macroscopic spray characteristic. The macroscopic description of emulsion fuel spray generally focused on the interaction of the latter and the control volume where it is injected and mixed, and because of this the fuel spray can be defined with the following physical parameters:

- i. Spray penetration length
- ii. Spray cone angle
- iii. Break up length

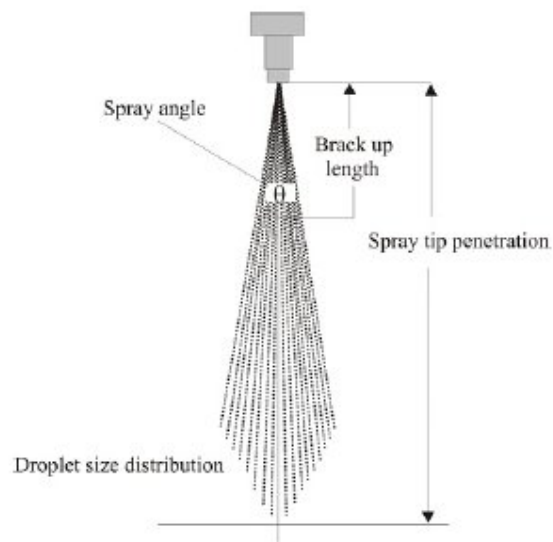


Figure 2.4: The definition of macroscopic spray characteristics
(Source: Hiroyasu and Arai, 1990)

Terminology of spray:

- i. Primary atomization/break-up –The break-up of liquid core into liquid ligaments
- ii. Secondary atomization/break-up –The break-up of liquid droplets into small droplets
- iii. Turbulent diffusion/dispersion –The random spreading of droplets
- iv. Turbulent modulation –The generation and change, modulation, of turbulent properties due to liquid/air interaction
- v. Droplet size distribution –The probability $P(r)$ of finding a drop in the interval $[r, r+\Delta r]$
- vi. Breakup length –The maximum distance at which a liquid core can be identified
- vii. Sauter Mean Diameter (SMD) – $\sum d^3 / \sum d^2$

As the liquid jet leaves the nozzle, it becomes turbulent and the outer surface of the jet breaks up into droplets. Lee (2006) and Park (2005) studied the effects of the split injection on the macroscopic development characteristics of diesel spray and effect of a split injection on spray characteristics for a common-rail type diesel injection system. They concluded that the region of spray tip penetration was affected by variations in ambient temperature conditions and in the injection pressure.

At the same injection pressure and mass, the spray tip penetration increased and the Sauter mean diameter (SMD) increased. As one move away from the nozzle, the mass of air within the spray increases, the spray diverges, its width increases, and the velocity decreases. The fuel droplets evaporate as this surface contact friction with the air. The longer tip penetration and larger cone angle are desirable for maximum air utilization and better combustion due to the increased spray area.

2.3.1 SPRAY PENETRATION LENGTH

According to Simón Martínez (2010) Spray tip penetration (S) is defined as the maximum distance from the nozzle to the tip of the spray and it is determined by two factors, first the momentum quantity with which the fluid is injected and second, the resistance that the idle fluid presents in the control volume, normally a gas. Due to

frictional effects, the liquid kinetic energy is transferred progressively to the working fluid. This energy will decrease continuously until the movement of the droplets depends only on the movement of the working fluid inside the control volume.

If the spray penetration is too long, there is a risk of impingement on the wall of the combustion chamber, which may lead to fuel wastage and the formation of soot. Increasing the ambient pressure was shown to decrease the spray tip penetration as well as the break-up length. Changing the ambient temperature had a minor effect on the spray tip penetration, due to a corresponding reduction in ambient density. However, a reduction in the spray angle was observed at higher temperatures, suggesting that the evaporation of the droplets was confined to the region on the outside edge of the spray.

Previous studies have shown that a spray penetration overcomes that of a single droplet, due to the momentum that the droplets located in the front of the spray experiment, accelerating the surrounding working fluid, causing the next droplets that make it to the front of the spray an instant of time later to have less aerodynamic resistance.

The spray tip penetration can be calculated by the formula developed by Dent (1971) was one of the pioneers in the study of spraying phenomena as shown below:

$$S(t) = 3.07 \sqrt{\frac{\Delta}{\rho}} \sqrt{t} \quad (2.1)$$

According to Hiroyasu and Arai (1990) the spray penetration can be determined as a function of the time. Two equations for describing the spray penetration are more realistic. When the spray first injected into the chamber, the initial velocity of the spray tip is much larger than the surrounding air. In this zone the penetration is described by an expression proportional to time, t , in other words; it has a constant velocity. At the next time step, when the spray velocity slows down, the penetration at this zone is proportional to the square root of time, $t^{0.5}$.

The differentiate time between these two time steps as breakup time can be calculated as:

$$< \quad S = 0.39 \frac{\overline{\Delta}}{\rho} \cdot t \quad (2.2)$$

$$> \quad S = 2.95 \frac{\Delta}{\rho} \cdot \overline{d \cdot t} \quad (2.3)$$

$$h = \frac{\circ}{\Delta} \quad (2.4)$$

The instantaneous spray tip velocity can be calculated as:

$$U () = -- \quad (2.5)$$

2.3.2 SPRAY CONE ANGLE

The cone angle is defined by Simón Martínez (2010) as the angle formed by two straight lines that stat from the exit orifice of the nozzle and tangent to the spray outline (sprays morphology) in a determined distance. The angle in a diesel spray is formed by two straight lines that are in contact with the spray's outline and at a distance equivalent to 60 times the exit diameter of the nozzle orifice. This angle usually is between 5 and 30 degrees. This determines greatly the fuel macroscopic distribution in the combustion chamber. In one hand, the increase in angle decreases the penetration and can cause interference between sprays (when sprays are injected using multi-orifice nozzles) in the same chamber favoring the merging of droplets.

The spray cone angle θ can be defined as:

$$-- = -4 \quad -- / \quad -- \quad (2.6)$$